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SURFACE IMPACT DETECTION AND SCORING

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LIST OF ABBREVIATIONS AND ACRONYMS

AFWTF Atlantic Fleet Weapons Training Facility

AILS Advanced Impact Location System

ANSI American National Standards Institute

ASROC antisubmarine rocket

ASW antisubmarine warfare

AURA Australian Underwater Range Activity

AUTEC Atlantic Undersea Test and Evaluation Center

BARSTUR Barking Sands Tactical Underwater Range

BMILS Bottom Mounted Impact Location System

BSURE Barking Sands Underwater Range Expansion

COTS commercial off the shelf

CPU central processing unit

DPSK differential phase shift keyed

DSP digital signal processor

EC Executive Committee

FACSFAC Fleet Area Control and Surveillance Facility

IIR infinite impulse response

IOC initial operational capability

KMISS Kwajalein Missile Impact Scoring System

KMR Kwajalein Missile Range

MINEX mine exercise

MILS Missile Impact Location System

NGSS Naval Gunfire Scoring System

NOTS Naval Ordinance Test Station

NUWC Naval Undersea Warfare Center

NUWCDIVKPT Naval Undersea Warfare Center Division Keyport

NUWCDIVNPT Naval Undersea Warfare Center Division Newport

PMRF Pacific Missile Range Facility

RCC Range Commanders Council

SADOT Splash Activated Deep Ocean Transponder

SCIUR San Clemente Island Underwater Range

SCORE Southern California Offshore Range

SDLS SUS Detection and Location System

SIT Surface Impact Tracking

SMILS Sonobuoy Missile Impact Location System

SPARC scalable processor architecture

SPC signal processor controller

TOTO Tongue of the Ocean

USG Underwater Systems Group

USL Underwater Sound Laboratory

USS Unattended Scoring System

VLA Vertical Launch ASROC

VME Versa Module Eurocard

INTRODUCTION

A proposed task concerning surface impact detection and scoring was submitted by the chairman of the Underwater Systems Group (USG) to the Executive Committee (EC) of the Range Commanders Council (RCC) at their 42d meeting in Huntsville, Alabama, on 27-28 April 1993. This proposed task, described in appendix A, was approved and designated task US-10, Surface Impact Detection and Scoring. This report describes the history of work in this field, the efforts that were performed during this task, and the results and conclusions that were obtained.

HISTORY

The results of previous literature searches (see references 1 and 2) in the field of surface impacts and water entry technology have indicated that there is a wealth of literature available on this subject. However, most of the early theoretical and experimental work dealt with the force history experienced by a missile during impact and entry. This work was performed with the express purpose of providing a missile designer with sufficient data to predict the forces on a missile during impact and the effect of these forces on its subsequent trajectory. With this data, the missile could be designed with the necessary structural rigidity and shape to enter the water intact and complete its underwater mission.

The earliest known study on the feasibility of detecting naval weapons at sea by using the sound of impact was performed in 1952 by the Naval Ordinance Test Station (NOTS) at the request of the Underwater Sound Laboratory (USL), which is now the Naval Undersea Warfare Center (NUWC) New London Detachment. The USL was interested in determining the ability to detect air-launched torpedoes with submarine listening gear and wished to obtain realistic records of water entry sounds for study and training purposes. This work was also extended at the request of the Harbor Protection Project of Yale University to include the impact sounds of typical mines.

In the mid-1960s to mid-1970s, a renewed interest was shown in locating the position of open-ocean missile impacts as evidenced by developmental work on the Advanced Impact Location

System (AILS), the Bottom Mounted Impact Location System (BMILS), and the Unattended Scoring System (USS). In addition, population encroachment and safety considerations indicated that the Navy's future use of land targets could be precluded which caused the initiation of development efforts on the Sea Target and the Surface Impact Tracking (SIT) System.

Since that time, a number of fixed systems such as the Missile Impact Location System (MILS) and portable systems such as the Sonobuoy Missile Impact Location System (SMILS) and the Splash Activated Deep Ocean Transponder System have been designed and developed to provide the capability of detecting and scoring various objects impacting the water surface. The most recent systems are the Naval Gunfire Scoring System (NGSS) which is scheduled for initial operational capability (IOC) in September 1995 at the Pacific Missile Range Facility (PMRF) and the Kwajalein Missile Impact Scoring System (KMISS) which is scheduled for IOC in September 1996 at the Kwajalein Missile Range (KMR), Kwajalein Atoll. Both of these systems are being developed by the Naval Undersea Warfare Center Division Newport (NUWCDIVNPT).

OBJECTIVE

At present, most USG member and associate member underwater ranges require or desire a capability for surface impact detection and scoring involving mine exercise sonobuoy drops, air-launched torpedoes, naval gunfire, and missile firings. Current capabilities in this area have generally been developed in an ad hoc manner to meet specific customer requirements at each of the ranges. The objective of this task is to establish a common approach for surface impact detection and scoring based on member and associate member inputs. Technical requirements such as types of impacts, accuracy and coverage area will be determined. Operational requirements such as level of automation and impact classification will be defined. The ultimate goal is to develop a single system design that will meet all of the requirements at the various ranges. Achievement of this goal will represent a major milestone in the ongoing efforts to establish common range hardware and software requirements. With a surface impact detection and scoring system standardized and the associated software baselined, overall life cycle cost to individual ranges can be substantially reduced. In addition, new developments and system enhancements can be shared between ranges, thereby, reducing the per-range cost of each improvement.

APPROACH

A survey questionnaire was developed and distributed to member and associate member ranges. This questionnaire, provided in appendix B, was designed to determine range requirements and performance characteristics for impact detection and scoring. In addition, existing techniques and available hardware and software used at member and associate member ranges were requested. Responses to the survey were organized to determine common requirements. Existing techniques were analyzed to determine approaches that could be implemented at other ranges. The end result of these efforts was a recommended approach using recently developed hardware and software.

RESULTS

All of the six member and associate member underwater ranges surveyed provided responses. Descriptions of the ranges and impact scoring systems currently being used, along with narratives of the responses to the survey, are provided in the following sections.

ATLANTIC FLEET WEAPONS TRAINING FACILITY

The Atlantic Fleet Weapons Training Facility (AFWTF) maintains and operates two contiguous underwater tracking ranges located off the island of St. Croix in the U.S. Virgin Islands. The smaller range, called the South Range, is located west of the island and consists of 30 bottom-mounted hydrophones that provide a coverage area of approximately 100 square nautical miles. The larger range, called the North Range, is located northwest of the island and provides an additional coverage area of 300 square nautical miles using 16 bottom-mounted hydrophones.

The AFWTF presently has an acoustic system that uses the bottom-mounted hydrophones. The system is called the SUS Detection and Location System (SDLS) and consists of eight digital recorders that are interfaced to a 286 PC. The menu driven software sets up the recorders, triggers them for a specific impact or explosion, analyzes the data, and determines the location using the "SPLISH-SPLASH" Range Program.

In response to the survey, the AFWTF requires impact detection and scoring of mines, sonobuoys, and air-launched torpedoes over the total area of 400 square nautical miles with an accuracy of ±10 yards. Operational requirements are for a fully automated, real-time system with identification of the type of impact a desirable feature.

ATLANTIC UNDERSEA TEST AND EVALUATION CENTER

The Atlantic Undersea Test and Evaluation Center (AUTEC) is maintained and operated by the Naval Undersea Warfare Center, AUTEC Detachment. The underwater range at AUTEC is called the Weapons Range and is located in the Tongue of the Ocean (TOTO) off the eastern coast of Andros Island in the Bahamas. The Weapons Range is divided into two instrumented sections. The larger section consists of 52 bottom-mounted hydrophones that are configured in a 5 by 15 nautical mile rectangle and provides a coverage area of up to 230 square nautical miles. A smaller section to the north consists of 14 hydrophones and provides an additional coverage area of approximately 120 square nautical miles.

The AUTEC has an acoustic system that uses the Weapons Range hydrophones. This approach employs a semiautomated, near real-time (1 to 2 minutes) system that uses a "man-in-the-loop" with a graphics oriented software program called "IMPACT." Signals exceeding a threshold within a dedicated frequency band for seven selected hydrophones are provided on a workstation. Using a cursor or by manual entry, an analyst determines which time of arrival data are used in the solution. A third option uses all possible arrival time data to generate solutions. The quality of the solution is based on how close the calculated depth is to the actual depth, that is, the surface. The program also has a number of other menu selectable options for various analyses of the data.

In response to the technical requirements, AUTEC requires impact detection and scoring of air-launched torpedoes with an accuracy of ±10 yards over the available coverage area provided by the Weapons Range hydrophones. An additional technical requirement is the capability to detect and score impacts in the presence of acoustic pingers operating in nearby frequency bands. Operational requirements call for a semiautomated, near real-time system with near real time defined as approximately 1 minute. Identification of the type of impact is not required.

NANOOSE RANGE

The Nanoose Range is maintained and operated by the Naval Undersea Warfare Center Division Keyport (NUWCDIVKPT). The range is a joint United States-Canadian facility located in the Strait of Georgia on the eastern side of Vancouver Island, British Columbia. The underwater instrumentation consists of 26 short-baseline hydrophone arrays that provide a coverage area of approximately 56 square nautical miles.

At the present time, there is no acoustical system, but a number of optical and radar systems are used for splash point location at the Nanoose Range. These three systems are described next.

1. Dual Cinesextant Track. This is an optical system that uses a spatially separated pair of cinesextants to provide manual azimuth and elevation readings for a bearing-bearing solution of the splash point.

2. Cinesextant With Radar Track Intercept. This approach uses the three "now" system with release on the third "now" to obtain the time of drop. A single cinesextant provides a bearing line to the splash which is intersected with the extrapolated aircraft radar track to provide an estimate of the water entry point.

3. Radar Extrapolation Using Ballistics. This is actually three systems that use the same technique. The aircraft radar track, the third "now," and either sonobuoy, torpedo, or mine ballistics are used to perform on-line estimates of the appropriate object's splash position. For torpedoes and mines, the positions can be compared to target locations or desired mine positions for exercise scoring. This procedure can also be used for simulated drops, because there is no requirement for an object to hit the water surface.

In terms of impact detection and scoring requirements, NUWCDIVKPT lists mines, sonobuoys, and air-launched torpedoes as the types of impacts with an accuracy of ±10 yards over the Nanoose 3-D tracking range area. A fully automated real-time system is desired and a semiautomated near real-time system is required. Both systems should provide a post-test, non-real-time, position-refinement capability. Identification of the type of impact is not required.

PACIFIC MISSILE RANGE FACILITY

The Pacific Missile Range Facility (PMRF) maintains and operates two contiguous underwater tracking ranges off the island of Kauai, Hawaii. The Barking Sands Tactical Underwater Range (BARSTUR) is located west of the island and consists of 42 bottom-mounted hydrophones which provide a coverage area of approximately 100 square nautical miles. The Barking Sands

Underwater Range Expansion (BSURE) is located northwest of the island and consists of 18 hydrophones which provide a coverage area of 880 square nautical miles.

The PMRF has an acoustic system that uses the BARSTUR hydrophones for impact detection and scoring. The system is a post exercise, non-real-time approach that uses tape recorded hydrophone data. The data from several hydrophone channels are replayed on an oscillograph recorder. By visual inspection, the impact transient signals are distinguished from reverberation, extraneous noise, and non-impact related events. Time differences of arrival of the impact between pairs of hydrophones are measured manually and input to a computer program which calculates the impact location.

In response to the technical requirements, PMRF listed mines, sonobuoys, air-launched torpedoes, vertical launch antisubmarine rockets (ASROC), and naval gunfire as the types of impacts. In addition, PMRF provided a number of other special applications for transient and continuous wave (CW) pulse type signals,

where their existing detection and location system has been used in the past, but either a fully or semiautomated system would be more timely and productive. These include generating fixes on Dukane pingers; detecting and locating a torpedo end-of-run squib for torpedo recovery; B-52 bomb scoring; UQC and transponder

surveys; tracking active sonobuoys; determining splash point and squib firing posits

for a rocket assisted penetrator; and determining the depth of implosion for certain devices. The PMRF did not provide inputs on the area of coverage and accuracy; however, it is presumed that the required area is consistent with the present tracking coverage at BARSTUR which is approximately 100 square nautical miles. Similarly, it is presumed that the required accuracy is consistent with that attained with the NGSS which is ±5 to ±10 yards.

With the exception of naval gunfire which requires a fully automated, real-time system, PMRF would prefer a semiautomated, near real-time system for the other applications, because the acoustic impact signature may not always be known in some cases. Ideally, the signals from several hydrophones would be provided on a monitor where an analyst would select the impact transients to be used in the position solution. This desired approach is similar to the system presently in use at the AUTEC.

SAN CLEMENTE ISLAND UNDERWATER RANGE

The San Clemente Island Underwater Range (SCIUR) is maintained and operated by the Naval Undersea Warfare Center, San Diego Site. The SCIUR is located off the northeastern side of San Clemente Island and consists of six bottom-mounted hydrophones that provide a coverage area of approximately 50 square nautical miles.

The SCIUR has an acoustical, an optical and a radar system for surface impact location. These systems are described below.

1. Acoustics. The acoustical system uses the six bottom-mounted hydrophones that are connected

to the range facility building. Sound pulses are received by the hydrophones and detected and demodulated by the signal processor. The locations are then displayed on the graphics system. The tracking area is limited to the hydrophone coverage area of approximately 50 square nautical miles.

2. Optics. The optical system is composed of three tracking stations. At each station, range personnel operate survey equipment called theodolites. At the time of impact, the tracking station operators will manually "fix" their theodolites onto the target. The theodolites' bearings are then sent to a range facility computer which determines the location.

3. Radar. The radar tracking system is composed of two fire control radars. The radar data is consolidated into one data package that is transmitted from a centralized site and received at the range facility. The data is demodulated and serially transmitted to the range computer for position calculation and display on the graphics system.

In response to the technical requirements, the SCIUR listed mines, sonobuoys, air-launched torpedoes, and vertical launch ASROCs (VLAs) as the types of impacts with accuracy requirements dependent on the object being tested. Ideally, this requirement is one-tenth of the accuracy of the deployment system; however, this requirement is not always feasible, and an accuracy of ±5 to ±10 feet would be a more practical requirement. The required coverage area is also based on the system being evaluated. For routine training on the deployment of mines, sonobuoys, and torpedoes, an area of 40 to 50 square nautical miles is sufficient. For larger scenarios with multiple exercises or concurrent system tests, an area of 100 to 150 square nautical miles would be needed. From an operational point of view, the SCIUR desires a fully automated, real-time system with a type of impact identification capability.

The SCIUR also recommends that the Fleet commands be contacted to determine their operational requirements for impact detection and scoring.

SOUTHERN CALIFORNIA OFFSHORE RANGE

The Southern California Offshore Range (SCORE) is maintained and operated by the Fleet Area Control and Surveillance Facility (FACSFAC). The underwater tracking range is located west of San Clemente Island and consists of 84 bottom-mounted hydrophones that provide a coverage area of approximately 660 square nautical miles. A planned shallow water range expansion in the Tanner and Cortez Banks areas will provide an additional 350 square nautical miles.

Although they have done some testing with a developmental system, the SCORE presently does not have an operational impact detection and scoring capability. They would like a system for scoring mines and determining the splash point of sonobuoys, air-launched torpedoes, and air-launched torpedo targets. Missiles and naval gunfire may be required in the future. The desired coverage area includes the entire underwater range along with a noninstrumented area where aerial mine exercises are presently conducted. The required accuracy is ±5 feet. On the operational side, a fully automated, real-time system is desired and an impact identification capability is not required. Other operational requirements include the ability to score up to 60 impacts with an average time interval of 15 seconds between drops and the ability to conduct antisubmarine warfare (ASW) exercises and mine exercises (MINEX) concurrently in separate areas of the range. An operational constraint was also provided stating that the present hydrophone coverage area was not the most desirable operational area for a MINEX.

SUMMARY

A summary of the technical and operational requirements obtained from the survey are provided in tables I and II and discussed in subsequent sections.

TABLE I TECHNICAL REQUIREMENTS				
Range Activity	**Types of Impacts**	**Area of Coverage**	**Location Accuracy**	**Other Requirements**
AFWTF	Mines Sonobuoys Torpedoes	400 nm^2	±10 yds	None
AUTEC	Torpedoes	75 nm^2	±10 yds	Score impacts in presence of pingers.
Nanoose	Mines Sonobuoys Torpedoes	56 nm^2	±10 yds	None
PMRF	Mines Sonobuoys Torpedoes VLA Gunfire	100 nm^2	±5-10 yds	Detect and track other transient and CW pulse type signals.
SCIUR	Mines Sonobuoys Torpedoes	50 nm^2	±5-10 ft	Area/accuracy dependent on system being

	VLA			evaluated.
SCORE	Mines Sonobuoys Torpedoes	8x8 nm^2	±5 yds	None

TABLE II **OPERATIONAL REQUIREMENTS**			
Range Activity	Level of Automation	Impact Identification	Other Requirements
AFWTF	Fully automated real time	Yes	None
AUTEC	Semiautomated near real time	No	None
Nanoose	Fully automated near real time	No	Semiautomated and post-test capability.
PMRF	Semiautomated near real time	Yes (NGSS)	Fully automated real time required only for naval gunfire.
SCIUR	Fully automated real time (desired)	Yes (desired)	None
SCORE	Fully automated real time	No	Up to 60 impacts in short timeframe. Concurrent ops.

TYPES OF IMPACTS

The types of impacts are those typically encountered during naval training exercises and include mines, sonobuoys, air-launched torpedoes and VLAs. In addition, PMRF requires a system, presently being developed, for scoring naval gunfire and desires a system for detecting and locating a number of other transient and CW pulse-type signals.

AREA OF COVERAGE

All of the ranges require a coverage area equivalent to the area of their underwater tracking range, probably because the majority of the present systems are acoustic and this is the coverage area currently available with the existing in-water assets. However, the present systems use only some of the hydrophones (typically an array of seven) and thus, the actual coverage area is smaller than the underwater range area although hydrophone selection allows it to be located anywhere within the total area. The SCORE also requires coverage in a noninstrumented area where aerial mine exercises are conducted.

ACCURACY

With the exception of the SCIUR, all the ranges require impact location accuracies on the order of ±5 to ±10 yards. These are reasonable values and typical of the accuracies from an acoustic type system. The ±5 to ±10 feet accuracy requirement for the SCIUR probably cannot be achieved with an acoustic system.

LEVEL OF AUTOMATION

Five of the six ranges either require or desire a fully automated, real-time system. The PMRF requires this capability only for naval gunfire and desires a semiautomated near-real-time systems for certain types of impacts and a post-exercise non-real-time system for others. The AUTEC prefers a semiautomated near-real-time system for all impact detection and scoring.

IMPACT IDENTIFICATION

Three of the six ranges expressed an interest in a system that provided identification of the impacting body. The AFWTF and SCIUR indicated that identification would be a desirable feature, while the PMRF stated that identification will be required for naval gunfire. This requirement has since been eliminated for the NGSS because of the high technical risk and cost of providing this capability.

CONCLUSIONS AND RECOMMENDATIONS

From the results of the questionnaire, it is apparent that all the ranges surveyed either require or desire an impact detection and scoring system. With the exception of SCORE, all the ranges have some type of system to provide this capability. The majority of these systems are acoustical and use the existing bottom-mounted hydrophones for detection of the impact transient. With the exception of the fully automated NGSS, all of the present systems are either semiautomated near-real-time or post-exercise non-real-time systems.

Based on the responses to the technical and operational requirements, any common system design should have the following performance characteristics.

The system should be capable of detecting and locating the impacts of bodies typically used in naval exercises including sonobuoys, mines, air-launched torpedoes, and VLAs. In addition, the capability to detect and locate nonimpact related events such as end-of-run squibs, implosions, and CW pulses from pingers, active sonobuoys, and transponders would be a desirable feature.

The area of coverage should be consistent with the underwater range area. It need not provide complete coverage of the entire area but should be capable of covering any preselected section of the total area at any given time. Additionally, it should have expansion capability, so the coverage area can be increased as needed. This capability appears to favor an acoustic approach over optics or radar; however, an acoustic approach does have some advantages. First, all the ranges have underwater assets in the form of bottom-mounted hydrophones for reception of acoustic signals, thus the procurement of any special radar system or optical equipment is not required. Second, an acoustic approach is not limited by weather or visibility which can happen with radar and optical systems. And finally, since a majority of the ranges presently use some form of acoustic system, they are familiar with this technique and may have hardware and software that could be adapted to a common system design.

An impact location accuracy of ±5 to ±10 yards should be sufficient for most naval training exercises and is consistent with the accuracy from an acoustic type system. If greater accuracy is required, the exercise may have to be tailored or additional equipment used to refine the impact solution.

The system should have a fully automated, real-time capability. For those ranges that prefer a semiautomated, near-real-time or a post exercise system, the real-time solution can be used as a "quick look" analysis with positional refinements provided during replay of tape recorded data.

The system should not be required to provide identification of the type of impact. During a typical naval exercise, the range should know the types of bodies being dropped or launched. The capability to discriminate between types of mines and sonobuoys would add unnecessary complexity and cost to the system. In addition, it is likely that a trained analyst with a sufficient data base would probably be more effective in identifing the type of impact from the acoustic signature.

Based on the previously defined performance characteristics, a common approach for surface impact detection and scoring can be proposed. The recommended approach, which meets all of the requirements, is the system currently being built to score missile impacts in the broad ocean area off Kwajalein Atoll. This system uses the detection and impact localization algorithms originally developed for the NGSS program. The system is fully automated but will also have a semiautomated or a post- test mode using the AUTEC "IMPACT" program. The heart of the system is a digital programmable acoustic signal processor, which is described in appendix C. Since it is programmable, it can be loaded with a variety of detection algorithms. At present, two tracking pinger (Mk-84 and Mk-72) algorithms and an impact detection algorithm are available; however, additional algorithms for detecting other acoustic sources can be programmed. The programmable signal processor is currently in use at PMRF for the NGSS. It will soon be implemented at the KMR for the KMISS program and at the AUTEC for replacement of the existing signal processors. A minimum system consisting of a hydrophone patch panel, an eight-channel signal processor, and a workstation and display can be provided at a cost not to exceed $200,000.

REFERENCES

1. B. E. Wall, "A Compendium of Water Entry Acoustics" (U), NUSC TR No. 4466, Naval Underwater Systems Center, Newport, RI, 28 December 1973 (CONFIDENTIAL)

2. B. E. Wall, "A Compendium of NUSC Studies in the Field of Water Entry Acoustics and Impact Scoring Systems" (U), NUSC TR No. 6000, Naval Underwater Systems Center, Newport, RI, 1 October 1981 (CONFIDENTIAL)

APPENDIX A

UNDERWATER SYSTEMS GROUP

PROPOSED TASK

1. **TITLE:** Surface Impact Detection and Scoring

2. **SCOPE AND SPECIFIC OBJECTIVES:** Establish a range-common approach for surface impact detection and scoring based on member and associate member inputs. Technical requirements such as types of impacts, accuracy, and coverage area will be defined. Operational requirements such as level of automation and impact classification will be determined. The objective is to develop a single system design that will meet all of the requirements at the various ranges.

3. **UTILITY OF END PRODUCT:** At present, most USG member and associate member ranges either require or desire a capability for surface impact detection and scoring during mine exercises, sonobuoy drops, air-launched torpedoes, and naval gunfire. In addition, both the Army (KMR) and Air Force (Patrick Air Force Base) have demonstrated an interest in a transponder based impact scoring system for missile firings. Current capabilities in this area have generally been developed in an ad hoc manner at each of the ranges. The development of a common approach for surface impact detection and scoring will represent a major milestone in the ongoing efforts to establish common hardware/software requirements between ranges. With a surface impact detection and scoring system standardized and the associated software baselined, overall life cycle costs to individual ranges can be substantially reduced. In addition, new developments and system enhancements can be shared between ranges, thereby, reducing the per-range cost of each improvement.

4. APPROACH:

a. Survey range requirements and performance characteristics for impact detection and scoring.

b. Analyze existing techniques and available hardware and software used at member and associate member ranges.

c. Develop common approach for detection and scoring.

d. Have member/associate member ranges review and comment on proposed approach.

e. Finalize hardware/software requirements.

5. **ASSIGNMENT AND MANAGEMENT:** The USG will perform this task with internal assignment of a task leader and committee members.

6. **OTHER RESOURCES:** None.

7. **MILESTONES:**

a. Task proposed Apr 93

b. Survey of member/associate member ranges Aug 93

c. Analyze existing approaches Dec 93

d. Develop common approach Mar 94

e. Solicit member/asssociate member comments Jun 94

f. Finalize hardware/software requirements Sep 94

g. Submit final report Nov 94

8. **PARTICIPANTS:** Barry Wall (NUWCDIVNPT), Albert Caron (AUTEC), Toby Ramos (AFWTF), Heidi Nevitt (SCORE), Rich Peel (NUWCDIVKPT), James Hager (PMRF), Ken Dorren (SCIUR).

9. **COORDINATION REQUIRED:** None.

10. **COMPLETION DATE:** Nov 94.

APPENDIX B

PRELIMINARY QUESTIONNAIRE

SURFACE IMPACT DETECTION AND SCORING

1. Does your range require or desire an impact detection and scoring system?

Yes _____ No _____

2. Does your range presently have some form of acoustical, optical, or radar system that detects surface impacts and determines their location?

Yes _____ No _____

3. If yes, please describe how the system works, how often it is used, and what hardware/software are available. (Use additional pages if necessary.)

4. Please respond to the following technical requirements:

(a) Types of impacts (check all that may apply)

Mines _____

Sonobuoys _____

Air-launched torpedoes _____

Missiles _____

Naval gunfire _____

Other _____ (list)

(b) Area of coverage

(c) Accuracy

(d) Other technical requirements?

5. Please respond to the following operational requirements:

(a) Level of automation required or desired

Fully automated, real time _____

Semiautomated, near real time _____

Post test, non-real time _____

(b) Impact classification (that is, identification of the type of impact required or desired)

Yes _____ No _____

(c) Other operational requirements?

6. Please provide any additional information or factors that may be pertinent to this study.

APPENDIX C

NUWCDIVNPT

PROGRAMMABLE ACOUSTIC SIGNAL PROCESSOR

The programmable acoustic signal processor was originally designed and developed by NUWCDIVNPT for the Australian Underwater Range Activity (AURA) and is presently being produced for the AUTEC Programmable Acoustic Signal Processor program, the Multiplexed Extended Sensor Array program, the Portable Tracking System program, the BARSTUR NGSS program, and the KMISS program. The only difference in the processors for all these programs is the number of digital signal processor (DSP) boards, which is dependent on the number of hydrophones.

Previous tracking range signal processors were based on inflexible, discrete, custom components that were hardwired to perform only one detection function. The new design uses state-of-the-art digital signal processing technology that allows a high degree of flexibility in resource allocation and algorithm implementation. It provides a platform that can incorporate new and advanced algorithms that enhance capabilities without any changes to the hardware. Additional advantages of this signal processor are that the hardware is commercial off-the-shelf (COTS) which enhances the life cycle support function. In addition, it is fully programmable providing the capability to develop, test, or make changes to various processing and detection algorithms. Finally, it is common to a number of other systems which means that any improvements to one system can be easily implemented on all the other systems. Descriptions of the signal processor hardware, software, and detection algorithms are provided in the following sections.

SIGNAL PROCESSOR HARDWARE

The processor is based on the Texas Instruments TMS320C40 digital signal processor chip, which is an upgrade to the TMS320C30 used at AURA. The new processor provides a 40-nanosecond cycle instruction time, a 50-million floating point operations per second, a single-cycle multiply and accumulate capability, 6 high speed communication ports, and 6 direct memory access controllers. The signal processor architecture consists of a Force scalable processor architecture (SPARC)-2CE central processing unit (CPU) board, a Bancom PCO3V IRIG reader board, an analog-to-digital clock board, a Spectrum TMS320C40 test ping generator board, and a number of Spectrum TMS320C40 DSP boards. The number of DSP boards depends on the number of hydrophone channels as described in a subsequent section. All the processor boards are standard, single slot, 6-U Versa Module Eurocard (VME) boards and are connected by a VME backplane.

The SPARC-2CE CPU board is used as the slot one controller and is responsible for controlling the data that flows into and out of the processor. The data and control information to and from the DSP boards are passed over a VME bus.

System time is provided by the IRIG reader board which translates either a recorded or actual IRIG-B or IRIG-A time reference standard into binary coded decimal time.

The analog-to-digital clock board provides a 118.227-kHz clock frequency to the analog-to-digital converters located on the DSP boards, a 1-pulse-per-second signal to the test ping generator board, and a time synchronization pulse to the IRIG reader board.

The test ping generator board provides various test signals at the input of the processor at a rate of 1 per second. The test signals are selectable in three different formats: a 12 target differential phase shift keyed (DPSK) ping format; a 6 frequency CW ping format, and an acoustic signal resembling a surface impact. Descriptions of these signal formats are provided in a subsequent section. These signals are stored in digital memory and converted to analog waveforms via an onboard clock and a digital to analog converter.

The DSP boards are commercial Octal C40 boards with eight TMS320C40 processors on each board. Each processor is equipped with a 64,000 x 32 bit, 0 wait-state, static random access memory. The TMS320C40 processors are arranged in pairs on standard Texas Instrument modules. Each module has a 128,000 x 32 bit programmable erasable read only memory, a 14-bit, 250-kHz analog-to-digital converter, and a 12-bit, 100-kHz digital to analog converter. Each board contains four modules which can be configured in two ways. If each module is dedicated to a single hydrophone, then only one mode of detection (that is, DPSK, CW, or impact) can be loaded and each board will support four hydrophones. If two modules are dedicated to a single hydrophone, then any two detection modes can be performed simultaneously and each board will support two hydrophones.

The boards are mounted in a self-contained, commercial, 19-inch VME chassis. The chassis can hold up to 21 boards. It is equipped with dual redundant power supplies with true load sharing and three vent fans. Power, voltage, and temperature monitoring are provided on the front panel. In addition, a liquid crystal diode graphic display is provided on the front of the chassis. This display is driven by the SPARC-2CE serial port and provides real-time feedback on the detection rates for all hydrophone channels.

SIGNAL PROCESSOR SOFTWARE

The SPARC-2CE uses standard SUN-OS. All control and display software is written in American National Standards Institute (ANSI)-C language. For maximum real-time efficiency, the TMS320C40 DSP software is written in assembly language. Other applications that are not time-critical are written in ANSI-C. A full suite of development tools are also provided. A SPARC based TMS320C40 emulator that supports on-line debugging of multiple processors is available along with a complete UNIX based assembler, linker, C-compiler, and library archiver.

The detection algorithm codes are loaded on the DSP boards through detection module software running on the SPARC-2CE. Three detection algorithms are currently available: a 19-bit DPSK ping detection algorithm; a 6 frequency CW ping detection algorithm, and an acoustic impact detection algorithm.

Detection data in the form of detection reports are passed to the signal processor controller (SPC) via an ethernet. The SPC can be run on any machine on the ethernet including the SPARC-2CE. The SPC acts as a server and provides detection reports to any client that requests the data. Standard software provided with the system allows real-time detection monitoring and a threshold control panel for the CW detection algorithm.

DETECTION ALGORITHMS

As stated previously, three detection algorithms are currently available. The DPSK ping detection algorithm is used to track surface and subsurface vehicles equipped with the Mk 84 tracking pinger, the CW ping detection algorithm is used for vehicles equipped with the Mk 72 tracking pinger, and the impact detection algorithm is used for detecting transient signals caused by surface impacts. Descriptions of the two ping detection algorithms and the impact detection algorithm are provided in the following paragraphs.

The DPSK signals are transmitted at a carrier frequency of 12.931 kHz in a phase-coded format achieved by 180 phase reversals of the carrier. The signal provides a target identification code (20 bits), ping identification (3 bits), and depth information (4 bits). Each bit is 541-seconds long and the total pulse length is 14.6 milliseconds. Incoming analog signals are sampled at a rate of 118.227 kHz, passed through a 3-kHz, digital, elliptical, infinite impulse response (IIR), band-pass filter centered at the carrier frequency, and then hard limited. The processor then differentially demodulates the 20-bit target identification using an "exclusive or" of itself delayed exactly 1 bit, resulting in a 19-bit code because the last bit in the sequence is compared to noise. The signal is then input to a correlator and compared to stored replicas of available target codes. A total of twelve 19-bit codes have been computer generated based on low autocorrelation sidelobe levels and low cross-correlation levels between the codes. The former provides a good time of arrival measurement off the autocorrelation peak while the latter provides a low probability of a false detection. If at least 17 of the 19 bits match one of the stored replicas, a valid detection is registered. Once the target code has been detected and the time of arrival measured, the ping identification and depth information are decoded on a bit-by-bit basis.

The CW signals can be transmitted at six different frequencies: 9.09, 13.51, 17.25, 23.81, 37.04, and 43.48 kHz. The regular signal consists of a 3 millisecond sinusoidal pulse at one of the frequencies. Every 8 seconds a 10 millisecond frame pulse is transmitted which provides a reference signal for sorting out subsequent pulse arrivals at the hydrophones. Incoming signals are digitized at the sampling rate of 118.227 kHz and input to a bank of six 2-kHz, digital, elliptical, IIR, band pass filters centered at each of the tracking frequencies. The outputs are rectified and then filtered in a 1-kHz, digital, elliptical, IIR, low-pass filter to eliminate ripple and provide the signal envelope. At this point, the significant features of the signal are the rising edge, the peak, and the falling edge. The rising edge is detected when the signal surpasses a noise variable threshold level, which is a combination of measured ocean noise and system operator input parameters. Once the threshold has been exceeded, the processor determines the peak signal level and the point where the falling edge is 33 percent below the peak. These two points are used to determine the pulsewidth. Pulses that meet predetermined pulsewidth criteria for a regular or frame pulse are considered valid detections.

The acoustic impact detection algorithm was initially designed and developed for the NGSS. Based on previous impact data and recent NGSS data analyses, it has been determined that the acoustic signatures of impact related events are typically strong and impulsive in the time domain, which leads to an increase in energy over a wide frequency band. This characteristic is put to use in a multiband impact detection scheme. Analog signals are sampled at a rate of 118.227 kHz and passed through a Martinez and Parks, low-pass decimation filter with a decimation factor of 3 and an upper frequency cut-off of 20 kHz. The filtered output is then input to a bank of three 2-kHz, digital, elliptical, IIR band-pass filters centered at 9.09, 13.51, and 17.25 kHz. The outputs of these filters are rectified and filtered in a 1-kHz, digital, elliptical, IIR, low-pass filter to provide the envelopes of the signals. These are then input to threshold crossing detection circuits. The threshold levels can be either fixed values or noise variable thresholds that are obtained by integrating the background noise level in each frequency band. A leading edge threshold crossing in any one of the frequency bands opens a detection window which is currently set at 240 seconds. At the end of this time, the window is closed and a detection report is generated. The detection report contains the detection threshold setting, the peak amplitude, the time of the peak amplitude, the rise time, and the pulse width above the threshold for each of the frequency bands where the threshold was exceeded.

The report also identifies which frequency band provided the earliest detection. Detection reports are passed to a computer over an ethernet.